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# RESEARCH MEMORANDUM

AN EXPERIMENTAL INVESTIGATION OF A FLAT RAM-JET

ENGINE ON A HELICOPTER ROTOR

By Robert D. Powell, Jr., and James P. Shivers

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NATIONAL ADVISORY COMMITTEE  
FOR AERONAUTICS

WASHINGTON

January 4, 1956

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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

## RESEARCH MEMORANDUM

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ENGINE ON A HELICOPTER ROTOR

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## SUMMARY


The propulsive and aerodynamic characteristics of a flat ram-jet engine suitable for use on a helicopter rotor have been determined on the Langley helicopter test tower and compared with results obtained in previous tests of an equivalent engine with circular cross section. As used in this report, "equivalent" means that the area distribution along the internal flow paths is approximately equal for the two designs.

The results obtained from the whirling tests indicate that the flat engine has higher values of propulsive thrust plus power-off drag than the circular engine. Furthermore, the flat engine has a lower specific fuel consumption than the circular engine because of the improved combustion resulting from longer fuel-particle burning paths obtained by a radial elongation of the combustion chamber and a nonuniform fuel injection which eliminates the adverse effects of whirling.

The power-off lift and drag characteristics indicate that the flat engine has lift-drag ratios about 3 times those obtained with the circular engine.

## INTRODUCTION

Previous tests (refs. 1 and 2) of helicopter rotors powered by ram-jet engines of circular cross section have indicated that the engine performance was considerably penalized by the distortion of the fuel spray pattern under the influence of high centrifugal accelerations. In addition, the rotor performance was penalized by the relatively low lift-drag ratios obtainable with the circular engine. In order to improve the rotor performance, the development of a ram-jet engine designed to meet the requirements of a helicopter rotor was undertaken. The design requirements for such an engine are that its propulsive characteristics be unaffected by high centrifugal accelerations and



that its aerodynamic efficiency approach that of an airfoil. A flat type of engine was chosen to meet these requirements. Flattening the engine should improve its lift and drag characteristics, and the radial elongation of the combustion chamber provides longer fuel-particle paths before contact is made with the outer engine wall, and thus improves combustion efficiency under high centrifugal accelerations.

Accordingly, flat ram-jet engines have been built and tested both in a free-air jet and whirling on a helicopter rotor on the helicopter test tower. This report discusses the propulsive and aerodynamic characteristics of the flat engine and compares the results with those obtained from previous tests of circular engines.

#### SYMBOLS

R	blade radius measured to tip of blade-engine or blade-engine-tab combination, ft
R <sub>1</sub>	rotor blade radius, 8.72 ft
R <sub>2</sub>	radius to center line of engine, 9.35 ft
b	number of blades
T	rotor thrust, lb
Q	rotor torque, lb-ft
ρ	air density, slugs/cu ft
Ω	rotor angular velocity, radians/sec
C <sub>T</sub>	rotor thrust coefficient, $T/\pi R^2 \rho (\Omega R)^2$
C <sub>TE</sub>	engine gross thrust coefficient, $\frac{F_p + D_j}{\frac{1}{2} \rho V_c^2 A_j}$ , lb
C <sub>Q</sub>	rotor-shaft torque coefficient, $Q/\pi R^2 \rho (\Omega R)^2 R$
A <sub>j</sub>	projected frontal area of flat ram-jet engine, 0.314 sq ft

S	plan-form area of tip configuration (engine plus outboard balancing surface), sq ft
$D_j$	total (internal, external, and interference) power-off drag of ram-jet engine plus outboard balancing surface, lb
$L_j$	lift of ram-jet engine plus outboard balancing surface, lb
V	velocity of ram-jet engine, ft/sec
$V_c$	corrected velocity of ram-jet engine, $V/\sqrt{\theta}$ , ft/sec
$\Delta C_{L_j}$	incremental lift coefficient of ram-jet engine plus outboard balancing surface, $\frac{\Delta C_T}{b/2} \frac{\pi R_1^2}{S} \left(\frac{R_1}{R_2}\right)^2$
$\Delta C_T$	incremental thrust coefficient of ram-jet engine plus outboard balancing surface, ( $C_T$ of blade-engine-tab configuration minus $C_T$ of blades alone)
$\Delta C_{D_j}$	incremental drag coefficient of ram-jet engine plus outboard balancing surface, $\frac{\Delta C_Q}{b/2} \frac{\pi R_1^2}{S} \left(\frac{R_1}{R_2}\right)^2$
$\Delta C_Q$	incremental torque coefficient of ram-jet engine plus outboard balancing surface ( $C_Q$ of blade-engine-tab configuration minus $C_Q$ of blades alone)
$F_p$	propulsive thrust of ram-jet engine (net force change less internal, external, and interference drag), lb
$W_f$	mass flow rate of fuel, lb/hr
S.F.C.	specific fuel consumption of ram-jet engine, $\frac{\text{lb/hr}}{\text{hp}}$
$W_{f_c}$	corrected fuel mass-flow rate, $W_f/\delta\sqrt{\theta}$ , lb/hr
$\delta$	ratio of absolute ambient pressure to standard NACA sea-level absolute pressure
$\theta$	ratio of absolute static temperature to standard NACA sea-level absolute temperature

## APPARATUS

The whirling tests were conducted on the Langley helicopter test tower, which is described in reference 3. The only major changes in the tower since reference 3 was written are an enlargement of the working areas at the base of the tower and the replacement of the Packard marine engine by a 3,000-horsepower variable-frequency electric motor drive. The installation of the rotor and flat ram-jet engine on the helicopter test tower is shown in figure 1.

The fuel and ignition system used for these tests is described in reference 1.

## Free-Air-Jet Thrust Stand

The free-air tests of the flat ram-jet engine were made on a static thrust stand at the base of the helicopter tower. The air supply was provided by the variable-frequency motor driving a compressor that forced air out of the nozzle shown in figure 2. The nozzle of the free-air jet was elliptical in shape with a major axis of 22 inches and a minor axis of 5 inches. The flat ram-jet engine was strut-mounted at 0° angle of attack in the air jet, approximately 14 inches from the nozzle. The strut mounting table, which was on antifriction rollers, was restrained by an electric strain-gage balance.

## Ram-Jet Engine

A sketch of the flat ram-jet engine is shown in figure 3. The engine had an overall length of 18 inches and a maximum width of 14.63 inches. The inlet and exit were nearly rectangular in shape, having parallel top and bottom surfaces and rounded sides. The cross-sectional area distribution along the internal flow path was approximately the same as for the circular engine. During preliminary testing the maximum engine thickness increased because of thermal and air loads, increasing the combustion-chamber cross-sectional area by about 10 percent. The maximum thickness of the ram jet as finally tested was 3.63 inches, with an inlet flow area of 0.077 square feet, a combustion chamber flow area of 0.304 square feet, and an exit area of 0.111 square feet.

The engine shell was made of 1/32-inch Inconel except for a 1/8- to 1/4-inch-thick reinforcing section at the attachment tab. The exit nozzle was made of 1/8-inch-thick stainless steel and was provided with four 1/8-inch-thick vertical stiffeners to prevent deformation.

Fuel was sprayed forward through six nozzles placed on 2-inch centers. The arrangement, which appeared to give uniform burning at the

centrifugal accelerations attained, consisted of four inboard nozzles rated at 3 gal/hr at 100 lb/sq in. with an 80° spray-cone angle and two outboard nozzles rated at 1 gal/hr at 100 lb/sq in. with an 80° spray-cone angle. This combination of nonuniform fuel injection was used to lessen the effects of the centrifugal accelerations by giving more efficient combustion. For the nonwhirling tests in the free-air jet, the nozzles were changed to spray an equal amount of fuel in order to obtain a symmetrical fuel-spray pattern. The nozzles for these tests were rated at 10.5 gal/hr at 100 lb/sq in. with an 80° spray-cone angle. This larger nozzle size was selected for the free-jet test stand, so that a fuel rate comparable to the whirling case could be achieved at the available fuel pressure, which was lower because of the absence of the pressure rise resulting from centrifugal force.

A thermocouple was mounted on a small sting attached to the top center of the engine so that it projected about 2 inches in front of the engine (fig. 3). The thermocouple was used to measure the inlet-air temperature rise caused by the exhaust of the preceding engine. Radiation effects from the combustion chamber were considered negligible.

#### Rotor

The rotor (described in ref. 1) was the same one used in previous tests of the circular ram-jet engines. The rotor blades were of all-metal construction, had a constant chord, and were untwisted. The blades had a radius of 8.72 feet (measured to the inboard side of the jet engine) and an NACA 0009.5 airfoil section. The static torsional stiffness of the blades was approximately 150 inch-pounds per degree of twist. A torsion electric strain gage was mounted on the blade spar approximately 1 foot outboard of the blade retention fitting.

A plan view of the engine-blade configuration first tested is shown in figure 4(a), but changes in the configuration were necessary because of flutter caused by a combination of low torsional stiffness of the rotor blade and the fact that the engine center of pressure was forward of the center of gravity of the engine. The first configuration consisted of a constant-chord blade, the engine, and a leading-edge fairing at the blade-engine juncture. This combination was used in obtaining the power-off drag values of the basic engine, but was limited by rotor-blade torsional flutter to a tip speed of about 340 feet per second.

In order to increase the allowable tip speed, the rotor was modified as shown in figure 4(b). In this arrangement, a 5-inch trailing-edge chord-extension was added to the outermost 12 inches of the blade. Also a trailing-edge fin, 56 square inches in area, was added to the outer shell of the ram-jet engine. This modification increased the tip

speed to about 450 feet per second before flutter occurred. The lift and drag characteristics of the ram-jet engine were obtained with this combination. Lift and drag values were also obtained with the engine in its normal condition (nozzles and flameholders in place); with the inlet blocked, with the exhaust blocked, and with the exhaust faired to a streamlined shape by adding a 3.5-inch-long wedge at the engine exhaust nozzle.

The tip speeds attained with the two configurations described were still too low for determining the propulsive characteristics of the ram-jet engine; therefore, in order to raise the allowable tip speed before flutter, a third configuration was tested (fig. 4(c)). The center of gravity of the engine was moved nearer its quarter-length point by the addition of 3 pounds of lead in the space formed by the inlet diffuser and the external shell of the engine. The attachment point was moved forward to keep the center of gravity on the quarter chord of the rotor blade. An outboard trailing-edge fin of 38.5 square inches was added to the engine as shown in figure 4(c). These changes resulted in eliminating flutter but the increase in tensile stress in the blade caused by the increased engine weight limited the tests to a maximum speed of 519 feet per second. At this speed propulsive data were obtained, as well as lift and drag values.

In all three configurations, the ram-jet engines were aligned with the blade airfoil section. The radial distance was 9.35 feet to the center of the engine and 9.98 feet to the outboard shell.

## METHODS AND ACCURACY

### Whirling Engine Characteristics

All measurements were obtained under steady-state rotor operating conditions and for wind velocities of 5 miles per hour or less. The test procedure was to establish a constant rotor tip speed by supplementing the torque provided by the ram-jet engines with the electric motor drive as rotor thrust was varied through the desired range by changing the blade pitch angle.

Propulsive characteristics.- For the engine operating conditions, the net torque change between power-on and power-off was obtained from the tower torque-measuring system. In previous tests, this net force change could not be measured directly, since the power-on rotor speeds were higher than those obtainable with the drive system. However, in this case, the torque corresponding to the net force change (power-on less power-off) could be obtained directly.

This net force change is the sum of the engine propulsive thrust and power-off engine drag (internal, external, and interference drag). Subtracting the measured power-off engine drag at a pitch angle of  $0^\circ$  gives the engine propulsive thrust. A fuel-pumping term corresponding to the force necessary to accelerate the fuel mass flow from zero velocity at the hub to engine speed was added to the whirling propulsive thrust, so that this propulsive thrust can be compared directly with that obtained with the engine in a free-air jet.

The propulsive thrust so determined is directly dependent on the drag of the engine. As the tests progressed, the combination of thermal and centrifugal stresses produced large ripples or bulges in the engine surface in a direction perpendicular to the air flow. This resulted in about a 50-percent increase in engine drag, but did not appear to affect the net force change from power-on to power-off. The ripples in the engine shell could have increased the burner internal friction losses. However, no losses in gross thrust were noted and this is attributed to the improved combustion caused by the increased turbulent flow, which thereby compensated for the increased friction losses.

The drag forces used in calculating the propulsive thrust presented in this report are those obtained from the initial tests of the smooth engine shown in figure 4(a). Consequently, the values of propulsive thrust reported are those that would have been obtained if the engine had not deformed.

A contamination effect which increased the temperature of the air through which the engine passed, caused by the exhaust of the previous engine, was determined and a correction for this effect has been applied. No correction was made for the chemical contamination of the air by the products of combustion in the engine path. The power-on performance has been reduced to that which would have been obtained under standard conditions by the method outlined in reference 4.

Lift and drag characteristics.- The power-off drag and lift characteristics of the ram-jet engines at various angles of attack were determined by measuring the difference in rotor torque and lift with and without the engines attached at a given tip speed and blade pitch angle. (For configurations, see fig. 4.)

The drag and lift values so determined include the increment corresponding to the total interference effects between the rotor blade and the tip engines. The flat ram-jet engine has been credited with all the additional lift obtained by the combination of blade and engine; however, part of the lift is due to the favorable end-plate effect of the ram-jet engine mounted on the rotor blade tip.

The method of determining the lift and drag characteristics requires a high degree of accuracy in obtaining the blade pitch, especially near the blade tip, where, because of the high velocities,



any small angle changes would have large effects. The blade pitch at the root was determined with a conventional control-position transmitter (slide-wire potentiometer) and the blade twist was determined with the torsion electric strain gage. The strain gage was dynamically calibrated by determining the twist of the rotor blade under typical test conditions. This was done by mounting a camera on the rotor hub and photographing the outer portion of the blade and ram-jet engine. The twist of the blade was obtained by comparing the measured blade root pitch and the engine pitch which was obtained by reading the camera film.

### Free-Air-Jet Thrust-Stand Tests

The thrust and fuel consumption of the flat ram-jet engine were also determined on a free-air-jet thrust stand for comparison with the values obtained under whirling conditions. The jet engine was strut-mounted at  $0^\circ$  angle of attack in the air jet approximately 14 inches from the nozzle. This distance was chosen because it was the closest distance at which the jet engine did not increase the static pressure in the free-air-jet nozzle. Thrust or drag forces were measured by the electric strain-gage balance.

The method of determining the propulsive thrust of the flat ram-jet engine on the free-air-jet thrust test stand was similar to that previously discussed for the whirling case. The propulsive thrust was obtained by subtracting the true engine power-off drag (as determined by the whirling tests) from the net force change (power-off to power-on) to eliminate test-stand strut tares.

The overall accuracy of all plotted results in this paper is believed to be  $\pm 3$  percent as indicated by scatter of the data.

## RESULTS AND DISCUSSION

### Propulsive Characteristics of the Flat Ram-Jet Engine

The variation of corrected propulsive thrust plus total power-off drag  $\frac{F_p + D_j}{\delta}$  obtained in the tower tests is shown in figure 5 as a function of fuel flow for the maximum tip speed obtainable with the configuration shown in figure 4(c). The corrected ram-jet velocity for the whirling flat engine was 488 feet per second. The actual velocity, uncorrected for temperature, was 519 feet per second. Curves of the propulsive thrust plus power-off drag obtained on the free-air-jet test stand at corrected velocities above and below the whirling velocity are shown for comparison with the whirling data. It should be pointed out that the whirling and free-air-jet data cannot be compared in the strictest sense, since the data shown for the free-air-jet tests were

obtained with the engines after completion of the whirling tests. The stresses due to whirling produced a progressive warp in the outermost 2 inches of the inlet diffuser, which may have slightly modified the propulsive characteristics of the engine in the free-air jet.

The curve of propulsive thrust plus power-off drag of the circular engine obtained from reference 1 is presented for comparison with the data obtained with the flat engine at approximately similar corrected velocities. It should be noted that the combustion-chamber cross-sectional area of the flat engine is approximately 10 percent greater than that of the circular engine as a result of bulging from thermal stresses and centrifugal forces. The inlet and exhaust areas of the two engines remained the same. The whirling data show that the flat engine has 17 to 50 percent higher values of  $\frac{F_p + D_j}{\delta}$  than the circular engine over the range of the fuel flow rate. These higher values are thought to be primarily due to the reduced effect of the centrifugal distortion of the fuel spray on the combustion efficiency of the flat engine. The effect of centrifugal force on the fuel spray is reduced by increasing the burning length of the fuel droplets (achieved by radial elongation of the combustion chamber) and by using a nonuniform nozzle arrangement which sprays more fuel to the inboard side of the engine. However, part of the increase may also be the result of increased combustion efficiency of the flat ram jet due to the lower combustion-chamber velocities resulting from the larger combustion-chamber area. An indication of this increase in combustion efficiency was obtained in free-air-jet tests at a corrected velocity of 600 feet per second. The data indicated that the propulsive thrust plus power-off drag of the flat engines was about 10 percent greater than that obtained with the circular engines under similar conditions.

The data of figure 5 have been replotted in figure 6 in terms of engine gross thrust coefficient in order to show more clearly the comparison between whirling and free-air-jet results. Curves of the propulsive characteristics obtained on the free-air-jet test stand at corrected velocities above and below the engine whirling velocities are shown. The curves indicate little or no effect of whirling on the propulsive characteristics of the flat engine up to a fuel flow rate of about 190 pounds per hour. It should be mentioned that the circular ram-jet engine would not run at fuel flow values above 200 pounds per hour, whereas the flat ram-jet engine gave no indication of unstable burning above 200 pounds per hour. No data were obtained at higher fuel rates since it was evident that the engine had reached its peak thrust.

The results shown in figure 5 are replotted in figure 7 in terms of estimated propulsive thrust against fuel flow rate. The propulsive-thrust values shown were obtained by subtracting from the values shown in figure 5 a power-off drag value for the engine without outboard

balancing tab. The comparison of the propulsive-thrust curves for the circular and flat engines shows less spread between the curves than in figure 5, because the flat-engine drag is larger than the circular-engine drag.

The effect of engine pitch angle on the propulsive characteristics of the engine is shown in figure 8 as a plot of the engine propulsive thrust and inlet air temperature rise against engine pitch angle for two representative fuel flow rates. It should be pointed out that these curves apply only for hovering out of range of ground effects. The curves for both fuel flow rates indicate a decrease in engine thrust as engine pitch is increased up to about  $2.5^\circ$ . As the engine pitch is increased past  $2.5^\circ$ , the engine thrust increases and tends to approach the values obtained near a pitch of  $0^\circ$ . At the higher fuel rates, the inlet-air temperature rise exceeded the range of the recording instrument. A calculated inlet-air temperature rise corresponding to the measured thrust decrease has been plotted as a dashed line to indicate the approximate values.

The maximum temperature rise occurs between engine pitch settings of  $2^\circ$  and  $3^\circ$ . Flow studies were made of the path of the engine exhaust by locating a smoke source in the engine and photographing the flow with a high-speed camera. The results show that at a blade pitch of  $0^\circ$ , the exhaust flow of the preceding engine rises up out of the path of the oncoming engine. As the pitch is increased to about  $3^\circ$  the exhaust leaves the engine, moves upward about 6 to 10 inches, and is then caught by the induced flow caused by the lift of the blade and engine and drawn down into the path of the oncoming engine. This induced flow seems to be primarily in a vertical direction with very little or no horizontal components such as those observed with the circular ram-jet of reference 1. As the pitch is increased further, the exhaust gases of the preceding engine are drawn down below the inlet of the incoming engine because of the increase in induced velocity. Even under conditions in which the flow studies indicate the exhaust of one engine missed the inlet of the next engine, there was a measured temperature rise of about  $50^\circ$  F. However, the shape of the temperature-rise curve indicates a marked reduction in inlet temperature rise as pitch is increased above  $3.5^\circ$ .

The variation in engine thrust is primarily due to the changes in inlet air-temperature rise; however, there is an indication of loss in thrust at the higher pitch settings at similar inlet air temperatures. This is most likely due to a decrease in engine diffuser pressure recovery caused by flow separation at the bottom inlet lip as the pitch angle is increased. This result indicates that if operation at pitch angles greater than about  $5^\circ$  is required, the inlet should be designed with inlet rake or mean line camber to avoid separation at the high angles of attack.

Figure 9 shows the lowest specific fuel consumption in pounds per hour per horsepower obtained with the circular engine and the undeformed flat engine, both whirling and in the free-air jet (only one free-air-jet value for the undeformed flat engine). The nonwhirling value of specific fuel consumption for the flat ram-jet engine obtained at 600 feet per second is similar to that determined for the circular engine. The data indicate considerably greater specific fuel consumption for the whirling circular engine than for the whirling flat engine at velocities up to 488 feet per second, which corresponds to a centrifugal acceleration of about 900g. The decreased specific fuel consumption of the whirling flat engine, as compared with the whirling circular engine, is due to better combustion resulting from the nonuniform fuel injection which eliminated the adverse effects of whirling for the radially elongated combustion chamber. Since no data are available, no definite conclusions can be drawn for the higher velocities.

#### Power-Off Aerodynamic Characteristics

Lift.— One of the main considerations that made the flat ram-jet engine appear attractive was that such a shape would have lift characteristics superior to those of an engine of circular cross section.

Figure 10 shows a comparison of calculated and experimental rotor thrust coefficients plotted against blade pitch at the 0.75R station. The main assumption used for the calculated curve was that the flat ram-jet engine and the various balancing surfaces had the same lift-curve slope as the blade airfoil section, 5.73 per radian. The outer 3 percent of the blade was considered as not producing any lift (tip-loss effect; see ref. 5), which has proved valid in previous comparisons. Figure 10 also shows a sketch of the areas considered subject to tip-loss effects. The figure shows that the calculated values predicted fairly accurately the results obtained from experimental data over the range of pitch angles. If the interference effects between the rotor blade and the engine are ignored, this agreement between experimental and calculated values indicates that the flat ram-jet engine has approximately the same lift characteristics as a blade airfoil section.

The effect of internal-flow blockage on the lift characteristics for the conditions of engine open with nozzles and flameholders installed, engine exit blocked, and engine inlet blocked is shown in figure 11 as a plot of incremental lift coefficients of engine plus outboard balancing surface for various blade angles. The data indicate no major change in lift coefficients of the engine due to the blocking off of the internal flow.

Drag.- The engine drag characteristics with fuel nozzles and flameholders installed, engine exit blocked, engine inlet blocked, and engine exit blocked and streamlined are shown in figure 12. This figure shows a plot of incremental drag coefficients of engine plus outboard balancing surface for various blade angles. A single point representing the drag of the engine without the outboard balancing surface attached at an engine pitch of  $0^\circ$  is also shown for the condition of engine open with fuel nozzles and flameholders installed.

The data show the incremental drag coefficient of the open engine with fuel nozzles and flameholders installed to be about 0.03 (based on the engine plan-form area of 1.797 square feet), which is roughly 3 times that which would be expected of an airfoil of similar plan form and thickness. The top curve is the incremental drag coefficient of the open engine with balancing surface attached (based on plan-form area of 2.185 square feet for the engine plus balancing surface with fuel nozzles and flameholders installed). At an engine pitch of  $0^\circ$ , the difference between the incremental drag coefficients of the engine with and without the balancing surface attached is almost entirely due to the change in plan-form area. The actual drag force of the engine alone at an engine pitch of  $0^\circ$  was increased about 3 percent when the outboard balancing surface was attached.

The middle curve shows the incremental drag coefficients obtained with either the inlet or exit of the ram-jet engine blocked. These two configurations gave a drag reduction of about 25 percent at an engine pitch of  $0^\circ$ . In order to determine the effectiveness of an exit fairing in further reducing the drag, a wedge fairing 3.5 inches long was added to the engine exit. This resulted in a further drag reduction of 40 percent. The incremental drag coefficient of the engine (based on plan-form area of 2.51 square feet for the engine, balancing surface, and exit fairing) is reduced to that which would be expected for an airfoil of similar thickness ratio.

Lift-drag ratio.- A comparison of the lift-drag ratios of the flat and circular engines (inlet and exit open with fuel nozzles and flameholders installed) is shown in figure 13. The measured values for the flat engine with balancing surface attached are shown, as well as a curve for the circular engine calculated from data presented in reference 1. A comparison of the two types of engines indicates that the lift-drag ratios of the flat engine are about 3 times those of the circular engine at engine pitch settings of  $4^\circ$  to  $5^\circ$ .

## CONCLUSIONS

Some of the propulsive and basic aerodynamic characteristics of a flat ram-jet engine mounted at the tip of a helicopter rotor blade have been determined on the Langley helicopter test tower. The nonwhirling propulsive characteristics of the isolated engine have also been studied on a free-air-jet test stand for comparison with the characteristics obtained under whirling conditions. The more significant findings of this investigation are as follows:

1. The whirling data indicate that the corrected values of propulsive thrust plus power-off drag for the flat engine are higher than those for an equivalent circular engine over the range of fuel flow rates of the tests. "Equivalent" means that the cross-sectional area distribution along the internal flow path is approximately equal for the two designs.
2. For conditions of hovering out of the range of ground effects, the propulsive thrust of the flat engine is reduced when the engine pitch angle is increased to about  $2.5^{\circ}$ . As the engine pitch is increased past  $2.5^{\circ}$  the thrust increases and tends to approach the values obtained near a pitch of  $0^{\circ}$ . Flow studies indicate that this variation in thrust may be due to changes in the inlet-air temperature rise caused by the exhaust of the previous engine, which was a maximum at an engine pitch angle between  $2^{\circ}$  and  $3^{\circ}$ .
3. The specific fuel consumption for the whirling flat engine is lower than that for the equivalent circular engine at velocities up to 488 feet per second, which corresponds to a centrifugal acceleration of about 900g. This reduction in specific fuel consumption of the flat engine can be attributed to the improved combustion resulting from the radial elongation of the combustion chamber and the nonuniform fuel injection which eliminated the adverse effects of whirling.
4. By assuming that the flat ram-jet engine (and its balancing surfaces) has the same lift-curve slope as the blade airfoil section, the rotor thrust coefficients for rotor powered by the flat ram-jet engine were accurately predicted. The interference effects between the rotor blade and the engine were not determined.
5. Blocking the engine inlet or exit reduced the engine power-off drag coefficient at  $0^{\circ}$  by 25 percent. A further reduction in drag coefficient of 40 percent was realized by installation of a wedge-shaped exhaust fairing.

6. The flat ram-jet engine had a lift-drag ratio about 3 times that of an equivalent circular engine at an engine pitch of  $4^{\circ}$  to  $5^{\circ}$ .

Langley Aeronautical Laboratory,  
National Advisory Committee for Aeronautics,  
Langley Field, Va., June 23, 1955.

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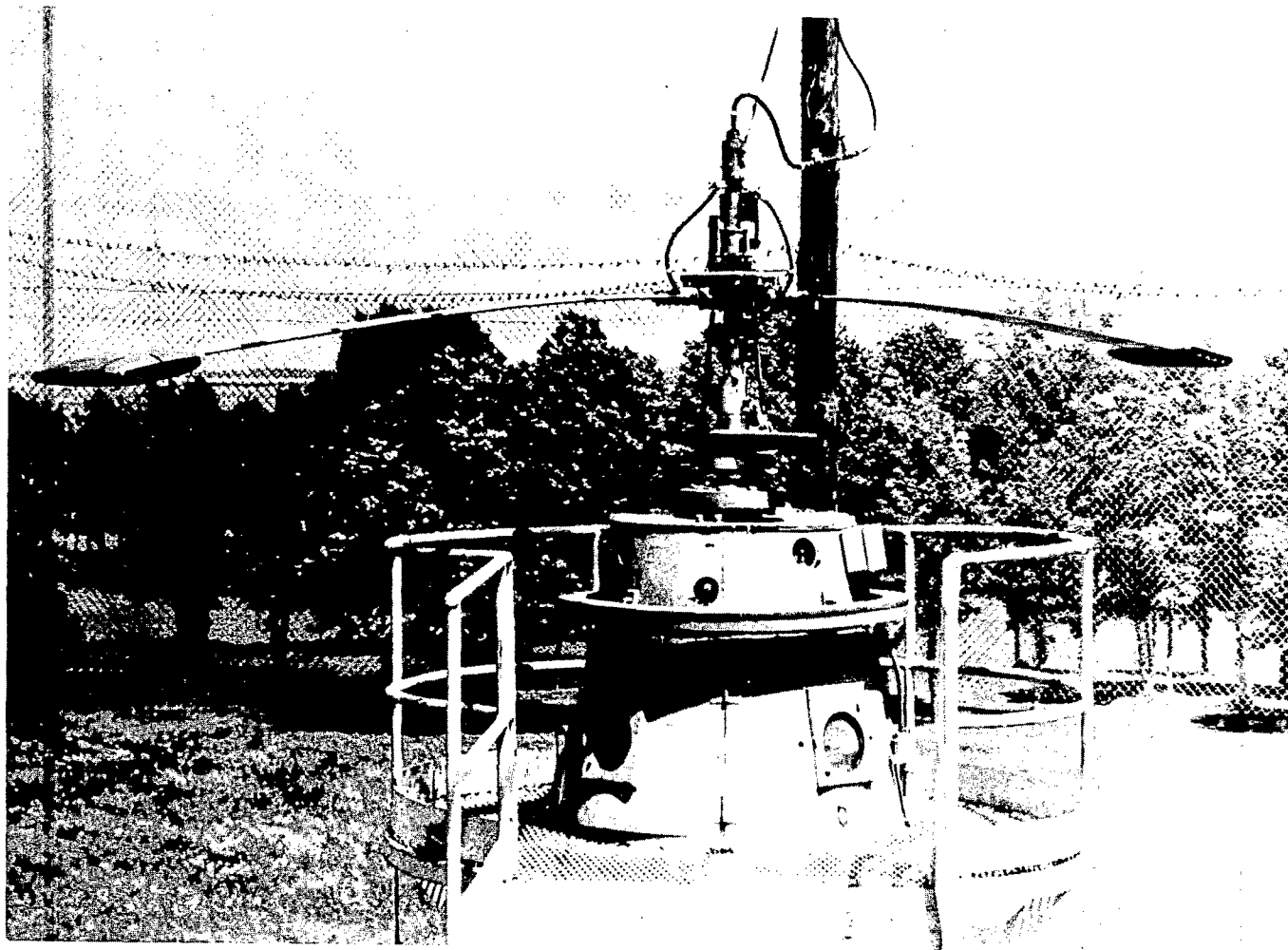


Figure 1.- Helicopter rotor powered by flat ram-jet engine, mounted on  
test tower. L-85142



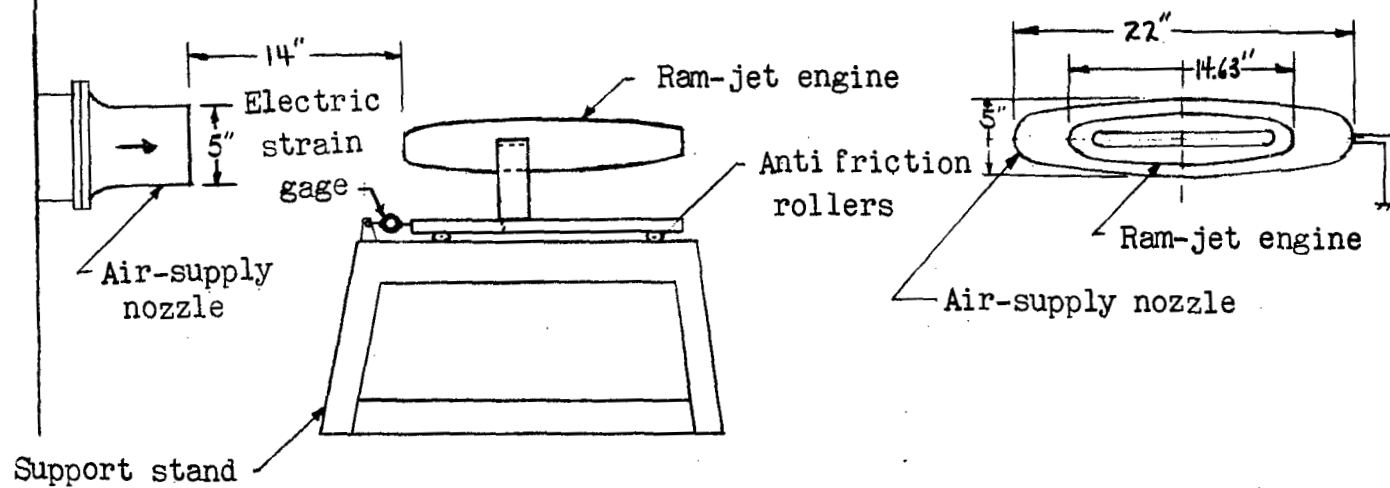


Figure 2.- Sketch of the static thrust stand at the helicopter tower.

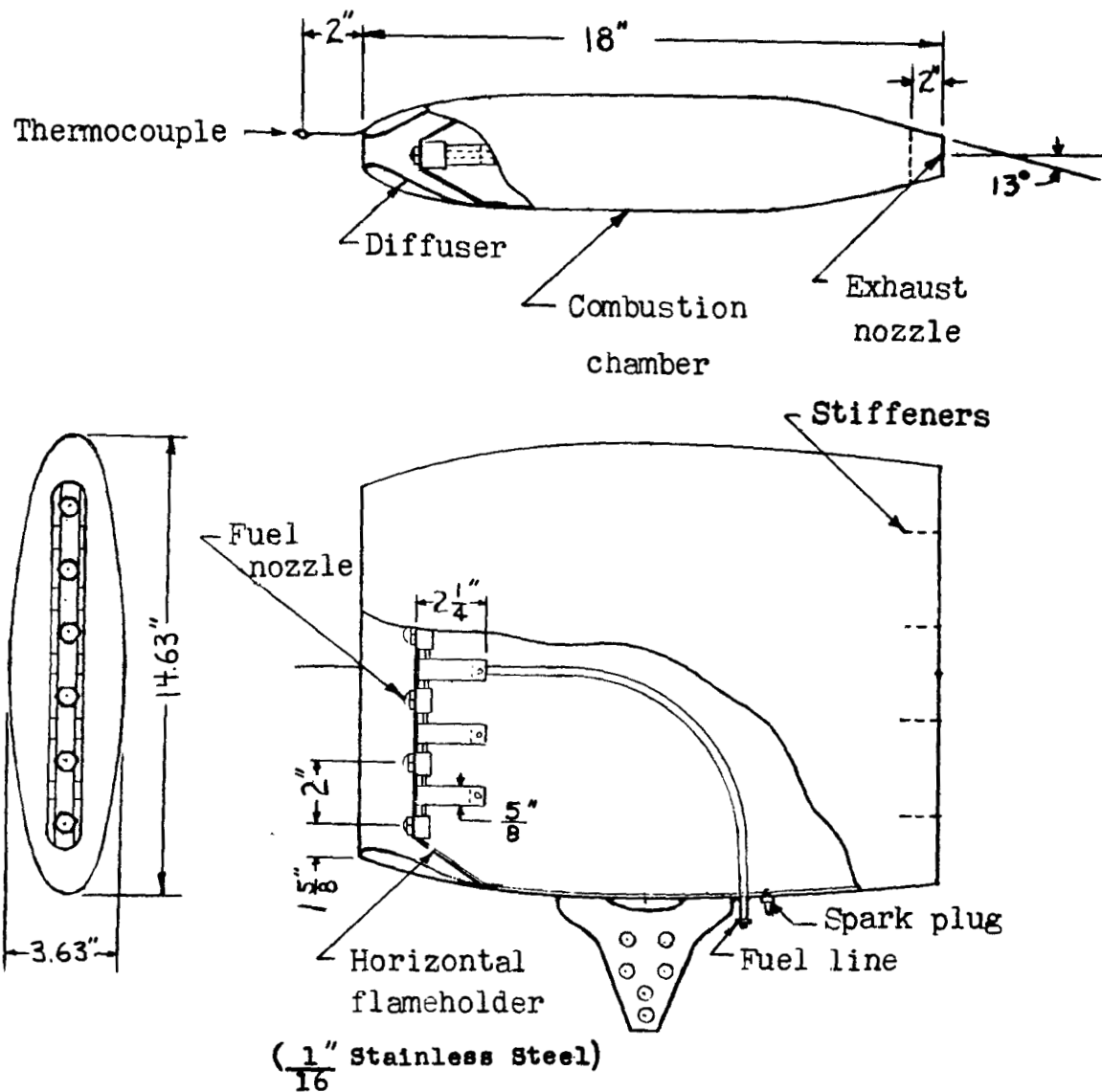
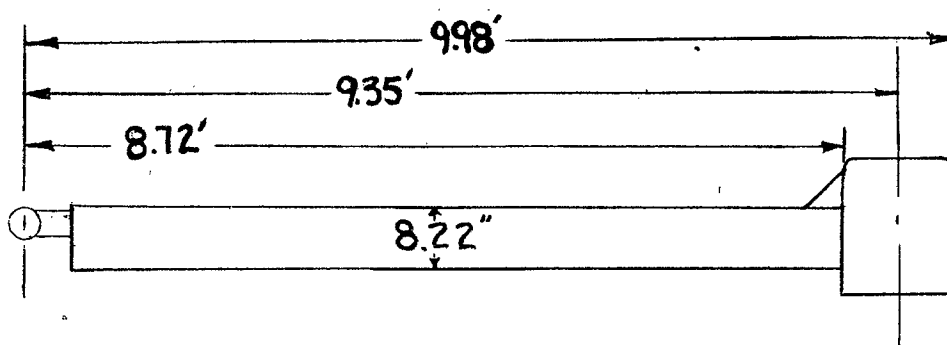
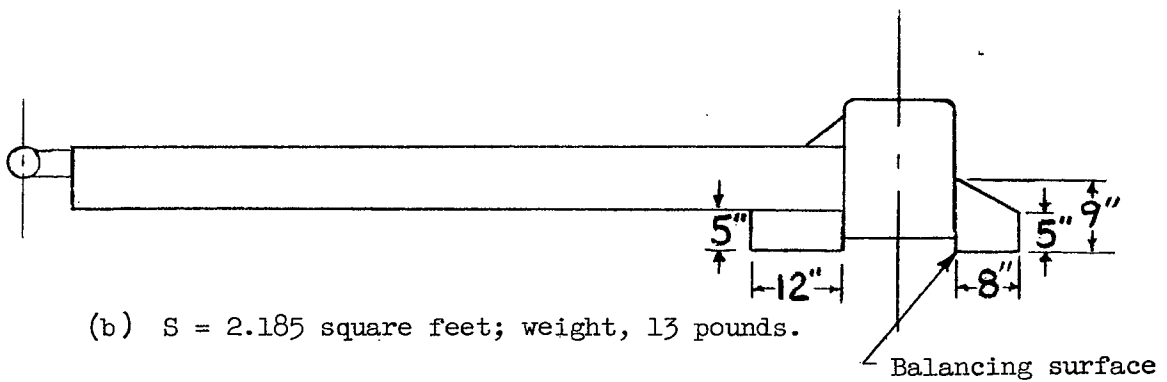


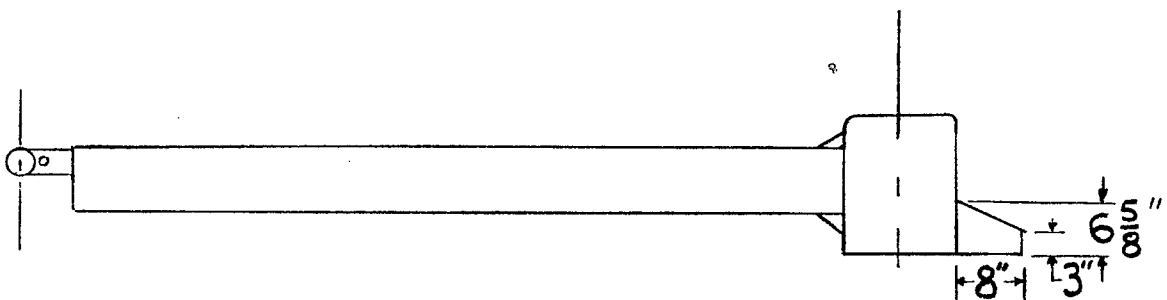
Figure 3.- Sketch of flat ram-jet engine.



(a)  $S = 1.797$  square feet; weight, 12 pounds.



(b)  $S = 2.185$  square feet; weight, 13 pounds.



(c)  $S = 2.064$  square feet; weight, 16 pounds.

Figure 4.- Plan views of the engine-blade configurations used.

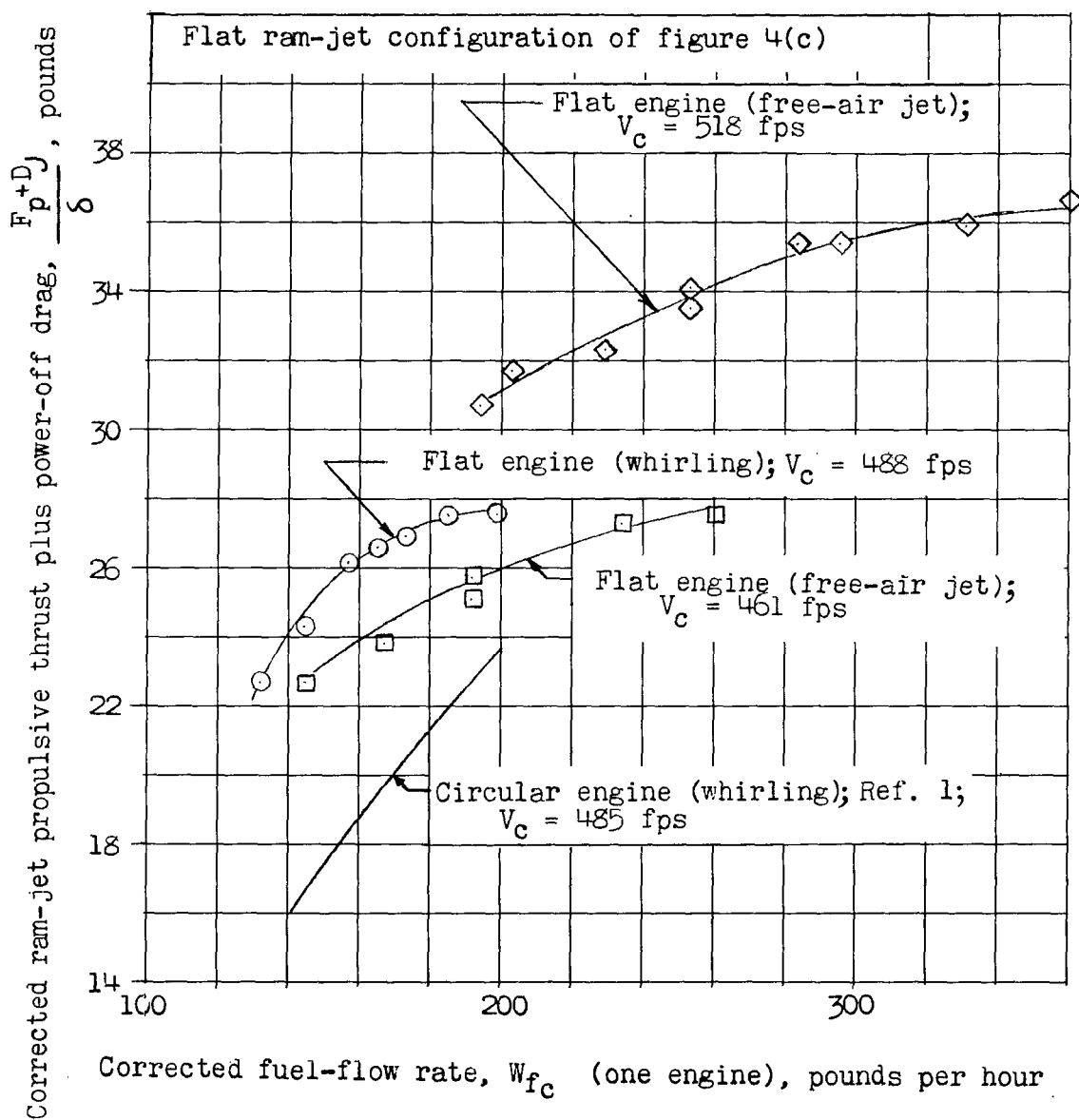


Figure 5.- Corrected ram-jet propulsive thrust plus power-off drag as a function of corrected fuel consumption for one engine.

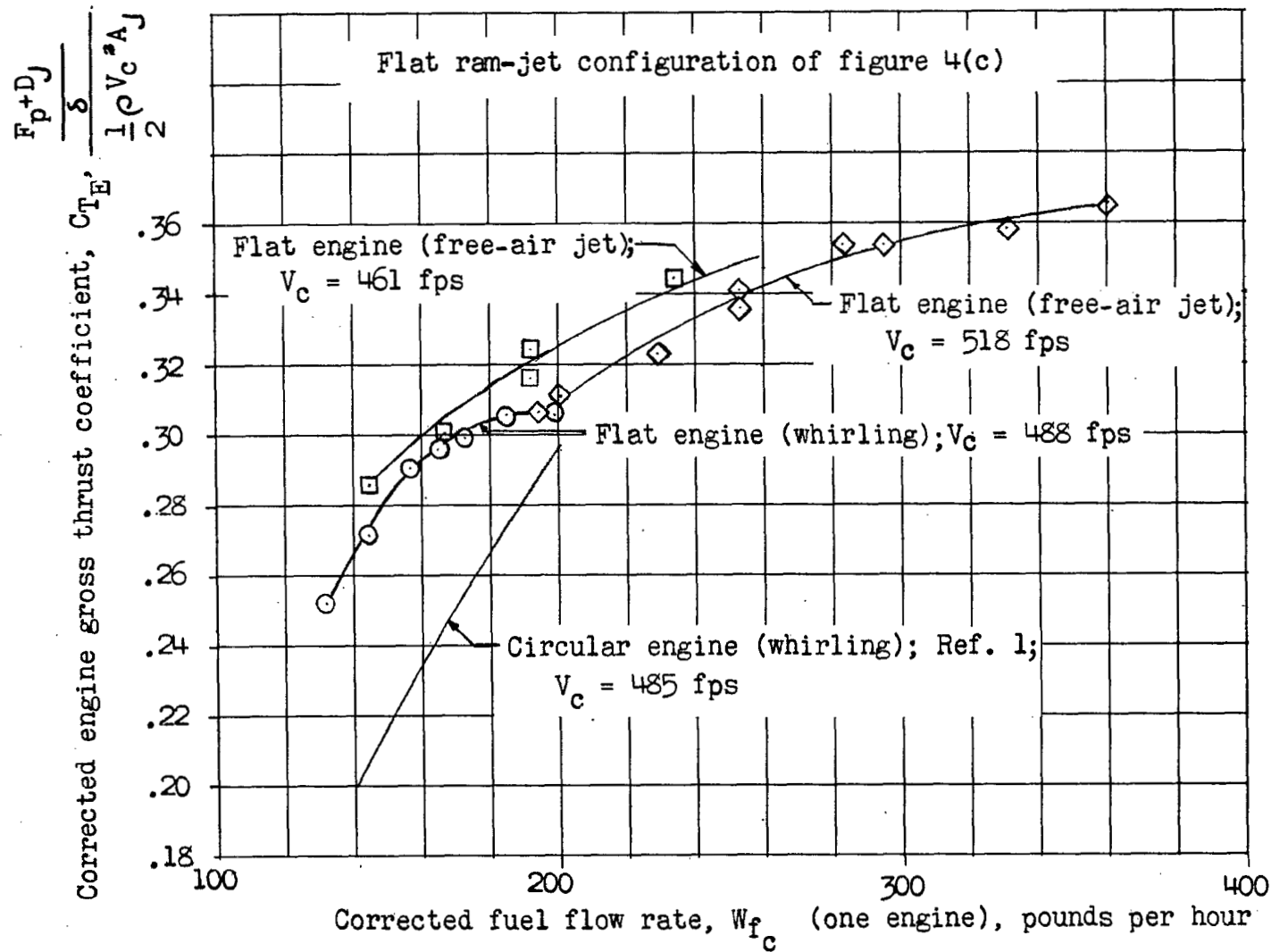


Figure 6.- Corrected engine thrust coefficient as a function of corrected fuel flow rate for one engine at a pitch angle of  $0^\circ$ .

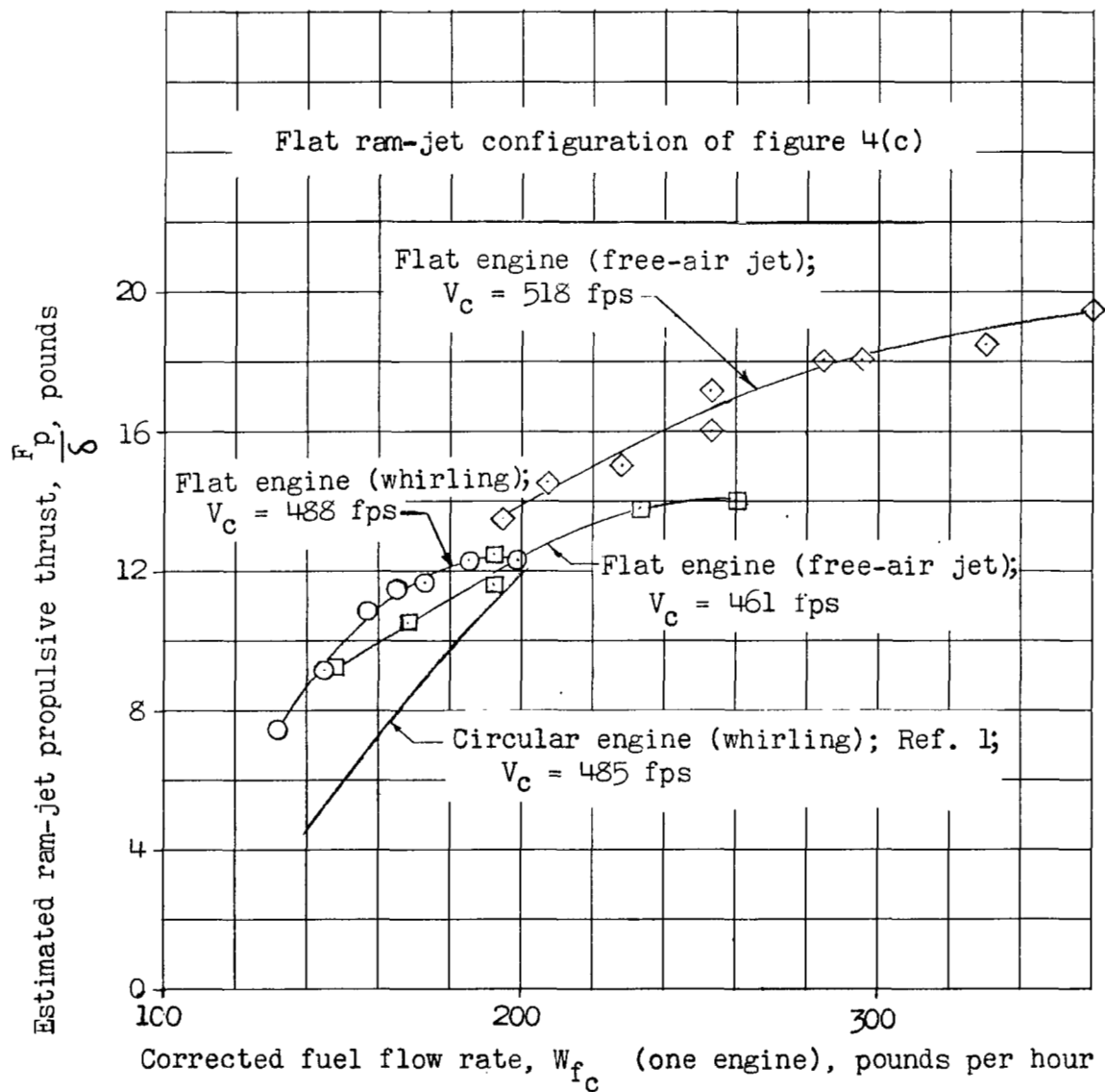


Figure 7.- Corrected ram-jet propulsive thrust as a function of corrected fuel consumption.

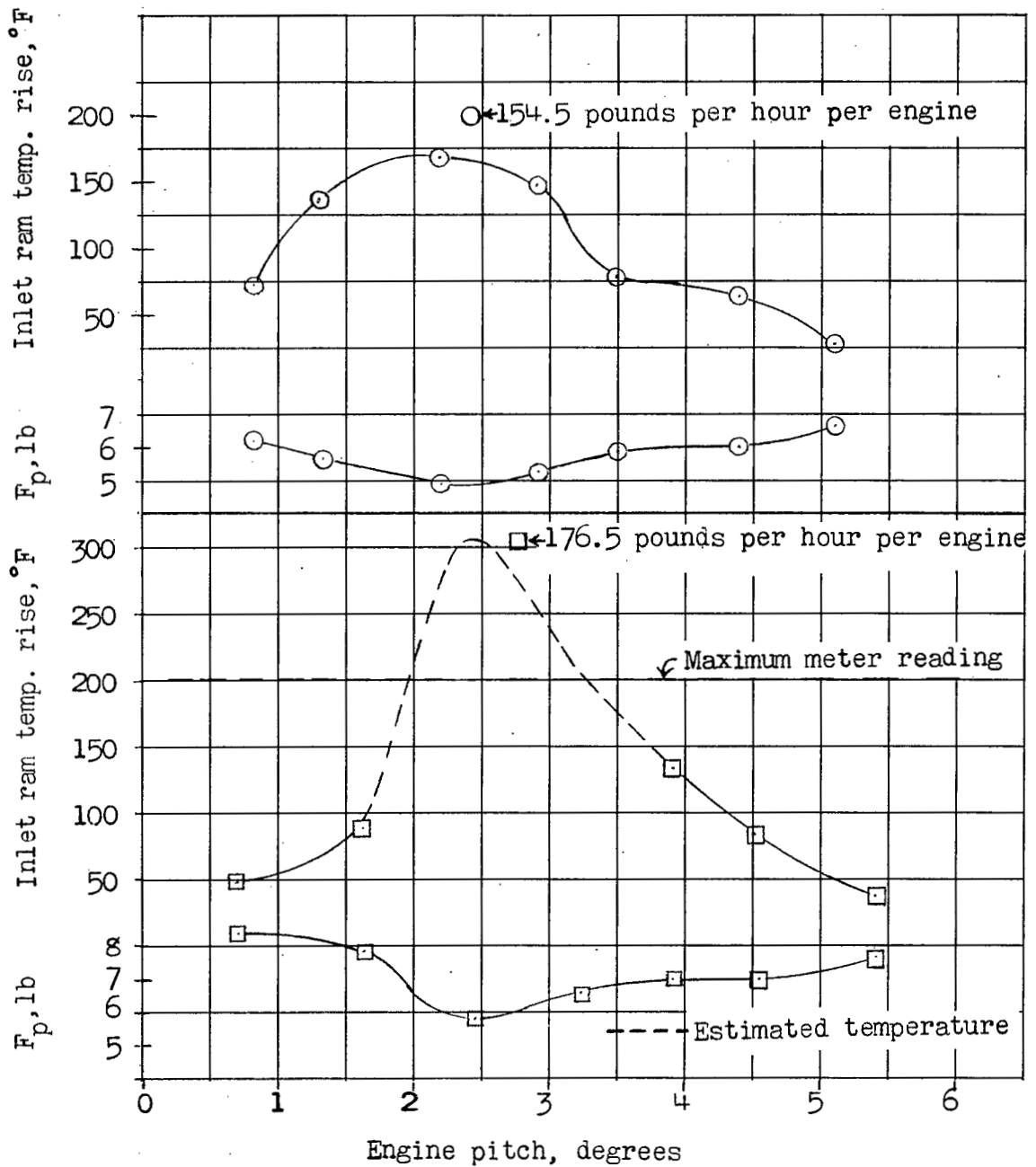


Figure 8.- Effect of engine pitch angle on propulsive thrust and inlet air temperature for two representative fuel rates at a jet-engine velocity (uncorrected for temperature variation) of 502 feet per second.

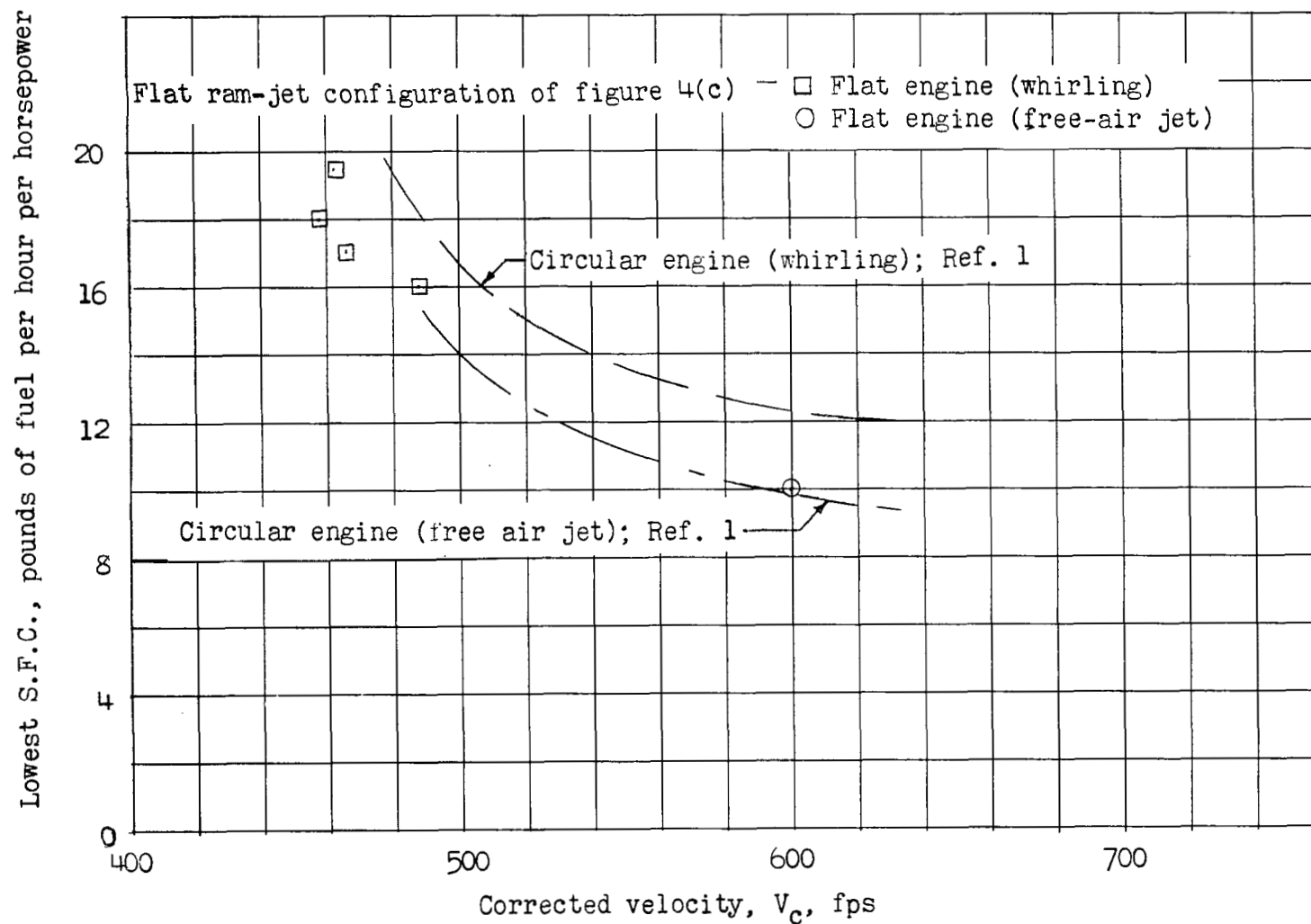


Figure 9.- Comparison of the lowest specific fuel consumption of the flat ram-jet engine with that obtained for a circular ram-jet engine, both whirling and in the free-air jet.



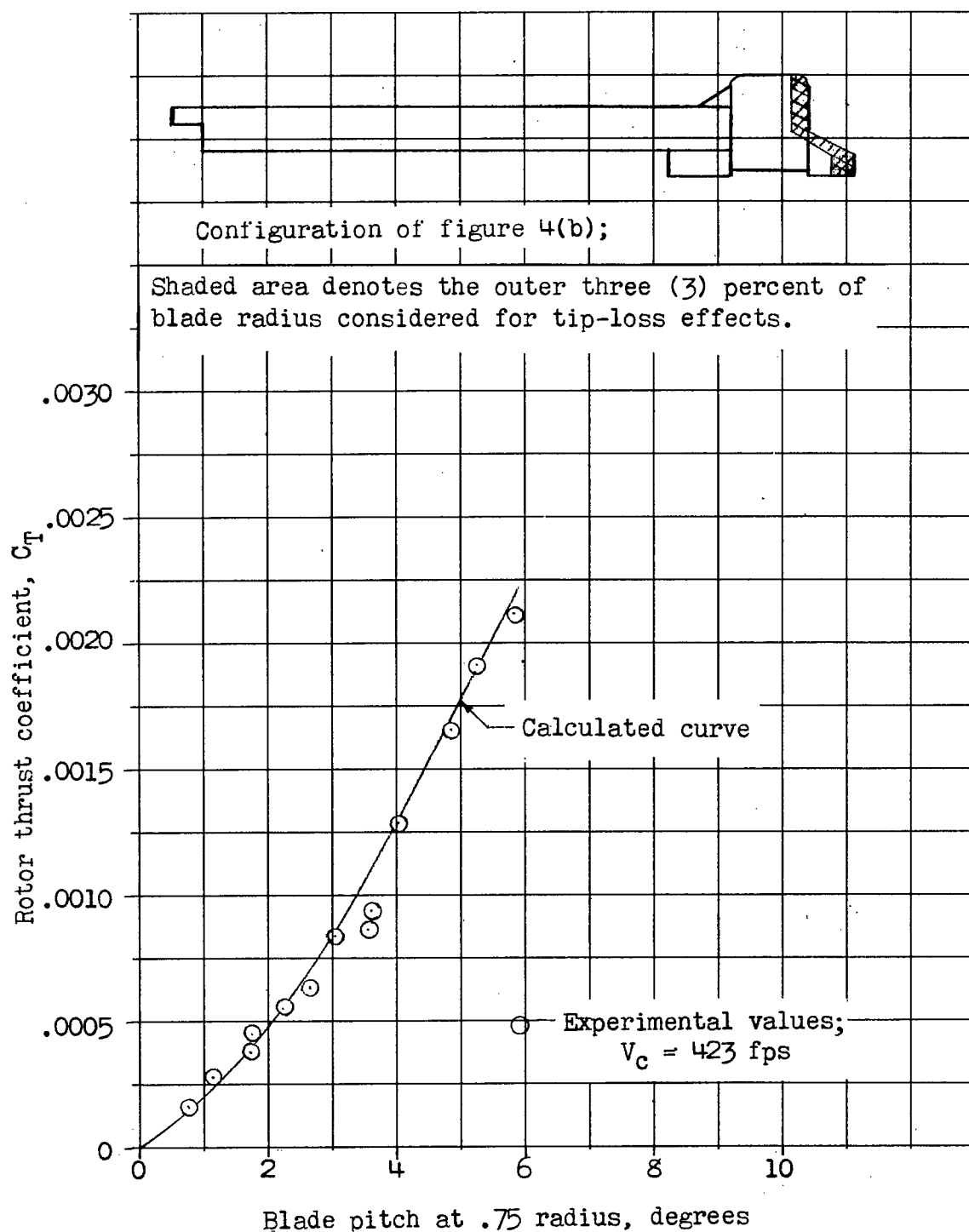


Figure 10.- Comparison of calculated and experimental rotor thrust coefficients as a function of blade pitch angle at 0.75R.

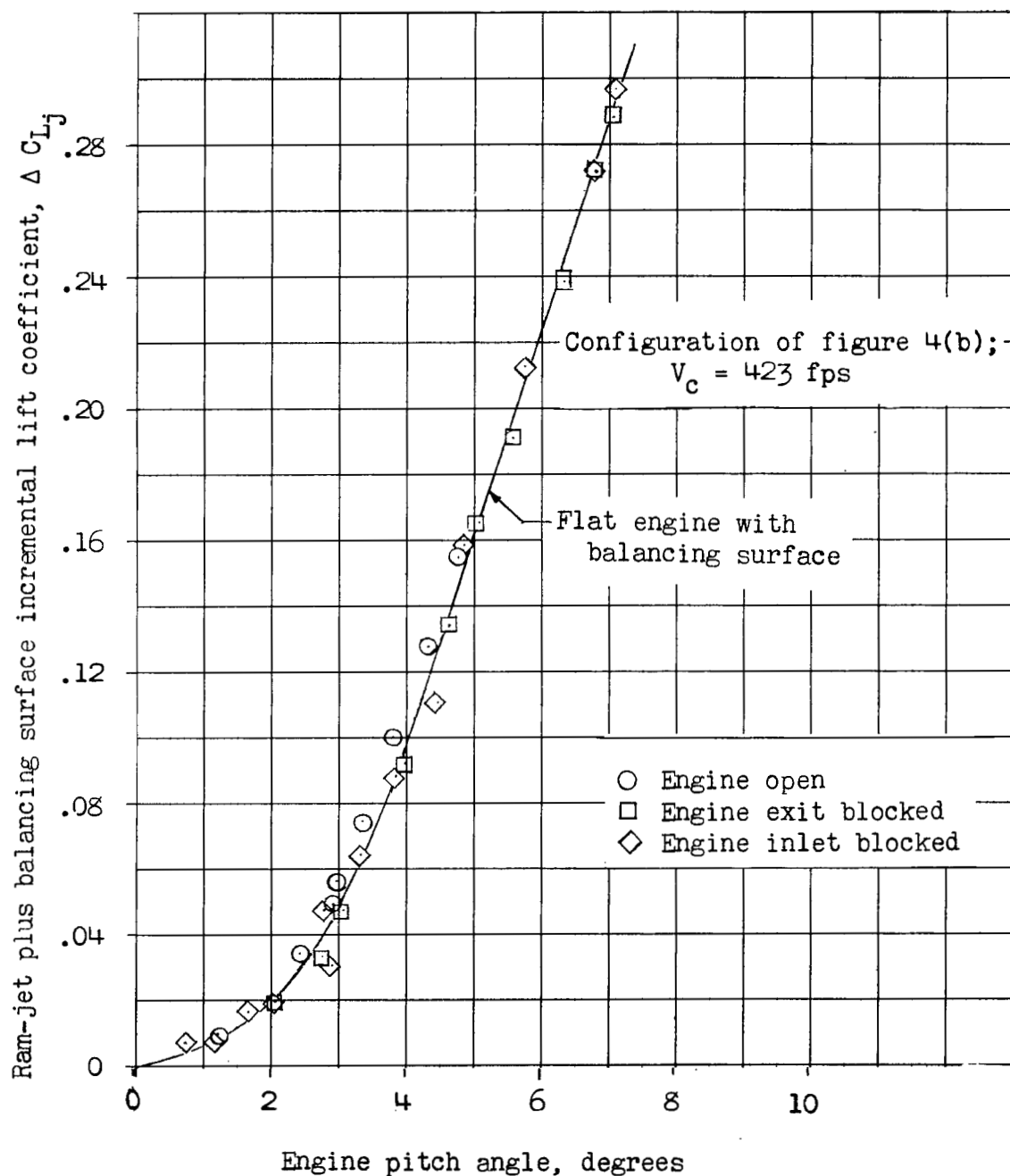


Figure 11.- Lift-coefficient increment of ram-jet engine plus balancing surface as a function of engine pitch angle.

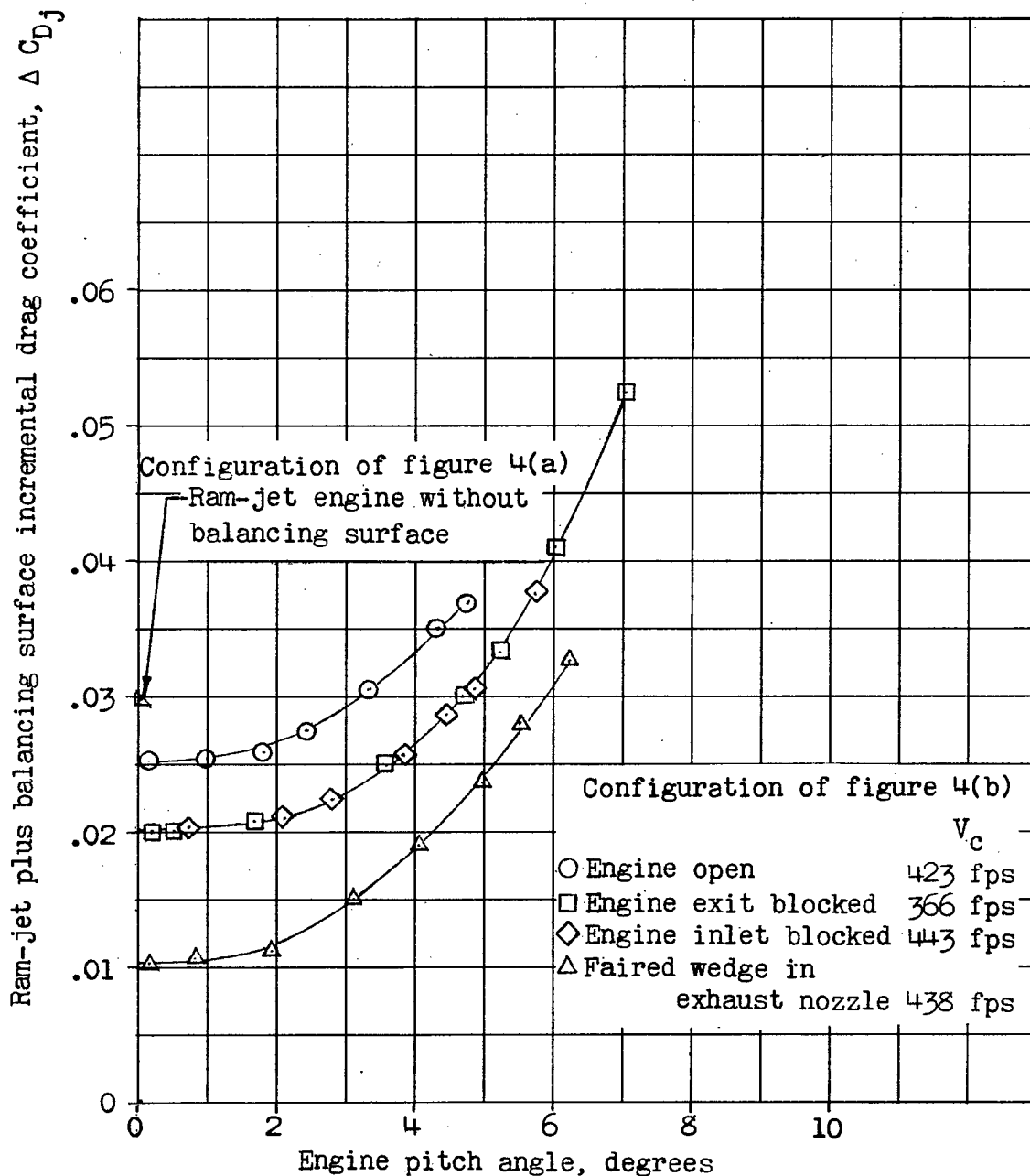


Figure 12.- Power-off drag-coefficient increment of ram-jet engine plus balancing surface as a function of engine pitch angle.

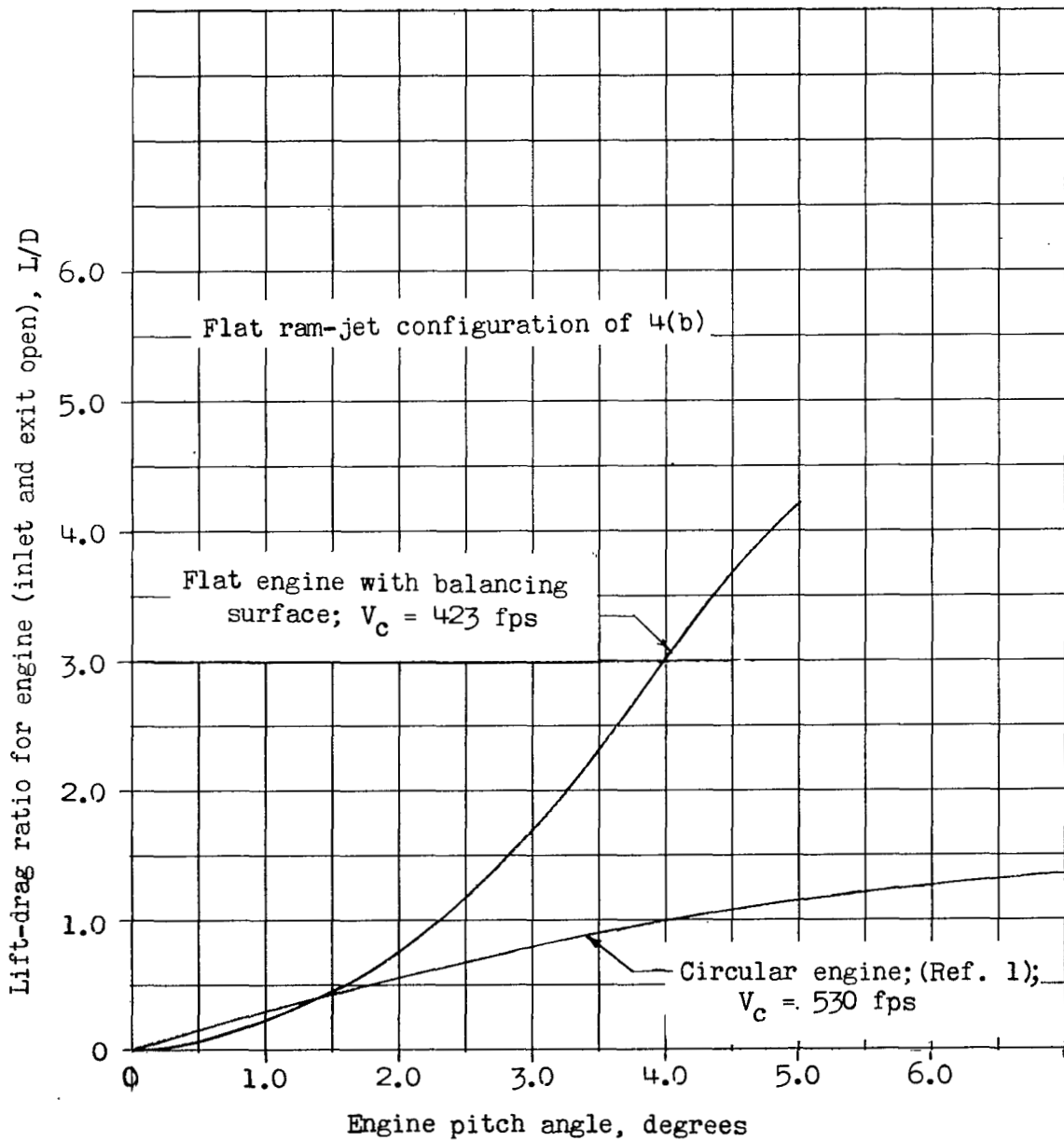
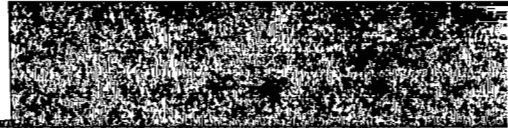


Figure 13.- Comparison of lift-drag ratios for flat engine (inlet and exit open) with those of the circular engine from reference 1.



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